

PATENT ABSTRACTS OF JAPAN

(11)Publication number : 11-204849
 (43)Date of publication of application : 30.07.1999

(51)Int.CI.

H01L 41/09
 B41J 2/045
 B41J 2/055
 B41J 2/16
 C04B 35/48
 H01L 41/22

(21)Application number : 10-008232

(71)Applicant : RICOH CO LTD

(22)Date of filing : 20.01.1998

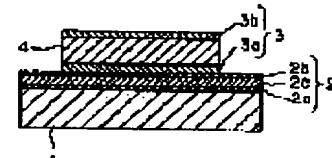
(72)Inventor : KOBATA YASUTAROU
 FUJISAWA ETSUKO
 AKIYAMA ZENICHI
 YAMANAKA KUNIHIRO

(54) PIEZO-ELECTRIC ACTUATOR

(57)Abstract:

PROBLEM TO BE SOLVED: To realize an actuator that can prevent lead diffusion to a board in sintering lead type piezo-electric ceramic material, on the Si board and also has mechanical strength and high reliability.

SOLUTION: An electric-mechanical converting element made of a piezo-electric material layer showing an electric-mechanical converting effect between an upper and lower electrode and the electrodes is mounted on a Si board. For an actuator to deform a part of the base 1 according to a given electrical signal, a middle layer 2 having more than one layer is formed between the electric-mechanical converting element. And the middle layer 2 is formed by a mono layer or plural layers composing of a function layer 2a touched with the base 1, an anti-reactive function layer 2b, and a film stress reductive function 2c.



LEGAL STATUS

[Date of request for examination]

[Date of sending the examiner's decision of rejection]

[Kind of final disposal of application other than the examiner's decision of rejection or application converted registration]

[Date of final disposal for application]

[Patent number]

[Date of registration]

[Number of appeal against examiner's decision]

of rejection]

[Date of requesting appeal against examiner's
decision of rejection]

[Date of extinction of right]

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CLAIMS

[Claim(s)]

[Claim 1] It consists of a piezoelectric-material layer which shows the electric - machine conversion effectiveness inserted on the base a vertical electrode and this inter-electrode one. In the electrostrictive actuator which allots electric-machine sensing-element section which transforms some bases according to the electrical signal given and by which the middle class of one or more layers is formed between a base and electric-machine sensing-element section. The electrostrictive actuator characterized by consisting of a monolayer in which this interlayer has the adhesion stratum functionale with a base, the reaction prevention stratum functionale, and the membrane stress relaxation stratum functionale, or two or more layers.

[Claim 2] It is the electrostrictive actuator characterized by for 1 micrometer or less of thickness of said adhesion stratum functionale being a metal oxide film 0.1 micrometers or less preferably in an electrostrictive actuator according to claim 1, and being the single crystal thin film which grew epitaxially to the orientation film or a substrate.

[Claim 3] It is the electrostrictive actuator which said reaction prevention stratum functionale is a metal oxide film 0.2 micrometers or less preferably [2 micrometers or less of thickness per layer] in an electrostrictive actuator according to claim 1, and is characterized by consisting of crystal film with a magnitude [of the microcrystal which can be found from XRD diffraction] of 50nm or more.

[Claim 4] It is the electrostrictive actuator which said membrane stress relaxation stratum functionale is a metal oxide film 1 micrometer or less preferably [10 micrometers or less of thickness per layer] in an electrostrictive actuator according to claim 1, and was characterized by porosity or becoming since amorphous.

[Claim 5] The electrostrictive actuator characterized by being the partial stabilization said whose interlayer contained at least one oxide of an yttrium, a cerium, magnesium, and calcium, or the zirconium dioxide film by which full stabilization was carried out in an electrostrictive actuator according to claim 1 to 4.

[Claim 6] The production approach of the interlayer of the piezo-electric actuator characterized by forming the zirconium dioxide film according to claim 5 by sputtering.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to the electrostrictive actuator using the piezoelectric device and piezoelectric device which are formed on Si substrate.

[0002]

[Description of the Prior Art] There is a piezo-electric ink jet head which applies a pressure to a pressurized room and carries out the regurgitation of the ink droplet as an application of piezo-electricity / electrostriction component. In recent years, as for the ink jet head, the actuator configuration with which it asks, and the etching technique is established and high integration forms a pressurized room in cheap Si substrate of cost with a semi-conductor process or a micro-machining technique is devised.

[0003] With the ink jet head of JP,8-252914,A, after forming SiO₂ film on a single crystal Si substrate and carrying out the laminating of elastic membrane and piezo-electricity / the electrostriction layer, the pressurized room for expulsion of an ink droplet was formed in Si substrate by anisotropic etching, BHF removed SiO₂ film further directly under a piezoelectric film, and the configuration and the manufacture approach that the effect by the counter diffusion of a piezoelectric film and Si substrate can be disregarded are proposed.

[0004] In Japanese Patent Application No. No. 107296 [nine to], the lead diffusion prevention film with precise part or oxidization zirconia film by which full stabilization was carried out, cerium oxide film, etc. was formed on the single crystal Si substrate, and the configuration of the ink jet head which leaves Si directly under a piezoelectric film is proposed.

[0005]

[Problem(s) to be Solved by the Invention] Many lead system electrostrictive ceramics ingredients, such as titanic-acid zircon lead (henceforth, PZT), are used for the piezoelectric-material layer of electric-machine sensing element. However, if annealing in the elevated temperature for sintering is performed for example, after forming PZT on Si substrate, lead will be spread on Si substrate and fusion by melting point lowering of SiO₂ currently formed in Si substrate front face will occur.

[0006] Although invention which solved the above-mentioned problem by removing completely Si substrate directly under a piezoelectric film and SiO₂ film by etching etc., and forming an ink pressurized room is indicated in JP,8-252914,A, in order to pressurize only by elastic membrane and the electrode layer, there is a problem that a mechanical strength becomes weak, by this invention.

[0007] In Japanese Patent Application No. No. 107296 [nine to], the mechanical strength for which a diaphragm is asked, and invention which can perform effective transfer of distortion of electric-machine transducer are indicated by forming the interlayer who consists of the precise part or the precise oxidization zirconia film by which full stabilization was carried out which prevents lead diffusion, cerium oxide film, etc. between electric - machine sensing element and a pressurized-room substrate, and setting the thin thick section of the pressurized-room section to 1-20 micrometers. However, although it is precise, and at least about 0.1 micrometers are possible if it is the perfect single crystal film which neither a defect nor a pinhole has when [like

an epitaxial film] forming an interlayer by the crystalline good monolayer since lead diffusion is prevented for example, film defects, such as a pinhole and a crystal defect, occur in practice, and the lead diffusion to Si substrate from there progresses. On the other hand, when the precise film which can prevent lead diffusion is thickly formed in a monolayer or a double layer, by the heat histories, such as piezoelectric-device baking, a crack progresses from a film front face and the lead diffusion to Si substrate occurs. The expulsion of an ink droplet by which the deflection of Si diaphragm by membrane stress was furthermore occurred and stabilized becomes difficult, and there is a problem that dispersion arises for every bit.

[0008] In this invention, from the monolayer which has the adhesion stratum functionale with a base, the reaction prevention stratum functionale, and the membrane stress relaxation stratum functionale, or two or more layers, the reliable base interface middle class with sufficient mechanical strength is formed, and it sets it as the main purposes to offer the electrostrictive actuator using it and electric - machine sensing element. Invention of claim 2 is that the adhesion force characterized by being the orientation film which consists of a metallic oxide, or the single crystal thin film which grew epitaxially to the substrate arranges the large base adhesion stratum functionale, and aims at forming the high interlayer of a mechanical strength.

[0009] Invention of claim 3 aims at forming a piezoelectric-material layer and the high interlayer of the reaction prevention effectiveness between bases by using the crystalline good metallic-oxide film precise as reaction prevention stratum functionale. Invention of claim 4 is arranging the membrane stress relaxation stratum functionale which negates the membrane stress produced from forming the precise reaction prevention film and the adhesion functional film, or is eased at an elevated temperature, and aims at making the whole interlayer's stress mitigate.

[0010] Invention of claim 5 aims at forming the middle class with more high toughness and a mechanical strength by using a part or the zirconium dioxide film by which full stabilization was carried out as a middle class ingredient. Invention of claim 6 aims at forming an interlayer more efficiently by using sputtering for interlayer formation.

[0011]

[Means for Solving the Problem] Invention of claim 1 consists of a piezoelectric-material layer which shows the electric - machine conversion effectiveness inserted on the base a vertical electrode and this inter-electrode one. In the electrostrictive actuator which allots electric-machine sensing-element section which transforms some bases according to the electrical signal given and by which the middle class of one or more layers is formed between a base and electric-machine sensing-element section It is the electrostrictive actuator which consists of a monolayer in which this interlayer has the adhesion stratum functionale with a base, the reaction prevention stratum functionale, and the membrane stress relaxation stratum functionale, or two or more layers.

[0012] In an electrostrictive actuator according to claim 1, the thickness of said adhesion stratum functionale is desirable 1 micrometer or less, and invention of claim 2 is a metal oxide film 0.1 micrometers or less, and is an electrostrictive actuator which is the single crystal thin film which grew epitaxially to the orientation film or a substrate.

[0013] In an electrostrictive actuator according to claim 1, said reaction prevention stratum functionale is [2, micrometers or less of thickness per layer] desirable, and invention of claim 3 is a metal oxide film 0.2 micrometers or less, and is an electrostrictive actuator which consists of crystal film with a magnitude [of the microcrystal which can be found from XRD diffraction] of 50nm or more.

[0014] In an electrostrictive actuator according to claim 1, said membrane stress relaxation stratum functionale is [10 micrometers or less of thickness per layer] desirable, and invention of claim 4 is a metal oxide film 1 micrometer or less, and since amorphous, it is porosity or a becoming electrostrictive actuator.

[0015] Invention of claim 5 is an electrostrictive actuator which is the partial stabilization said whose interlayer contained at least one oxide of an yttrium, a cerium, magnesium, and calcium, or the zirconium dioxide film by which full stabilization was carried out in an electrostrictive actuator according to claim 1 to 4.

[0016] Invention of claim 6 is the production approach of the interlayer of the piezo-electric

actuator which forms the zirconium dioxide film according to claim 5 by sputtering.

[0017]

[Embodiment of the Invention] Below, the configuration of this invention is explained with reference to a drawing. The schematic diagram of the piezoelectric-device unit which can apply this invention to drawing 1 is shown. On a base 1, the piezoelectric-material layer 4 which shows the electric machine conversion effectiveness inserted between vertical electrode 3a and 3b with the interlayer 2 is formed, and some bases are made to transform to electric-field impression. Furthermore, as shown in drawing 2, when the pressure room 5 is formed in some substrates 1 corresponding to a piezoelectric device and a nozzle plate 6 is joined to it, the ink jet piezo-electricity head by which the ink in a pressure room is breathed out is constituted from a nozzle 7 by the electric-field impression to an electrode.

[0018] A base 1 has a high mechanical strength, and it is excellent in workability, and as long as it is an ingredient inactive with heat treatment and burning temperature, it is not regulated especially, and it may be Si base, or may be the ceramics, or you may be a metal, and it may consist of the structures by two or more ingredients.

[0019] Elevated-temperature melting point noble metals, such as platinum and platinum group metals (Pd, Rh, Ir, Ru), and the electrode material which uses those alloys as a principal component are [that what is necessary is just the conductor which bears the high-temperature-oxidation ambient atmosphere in heat treatment and burning temperature as an electrode material] the most desirable from the point of stability.

[0020] The PZT system ceramics is desirable in the piezoelectric-material layer 4 on a lower electrode layer, and can form 10 thru/or 20-micrometer thickness in it by one presswork using screen printing. It is calcinated in atmospheric air at the temperature of 700-1000 degrees C after desiccation.

[0021] An interlayer 2 consists of adhesion stratum-functionale 2a [with a base 1], reaction prevention stratum-functionale 2b, and membrane stress relaxation stratum-functionale 2c. In order to heighten the reaction prevention effectiveness, two or more laminatings of the reaction prevention stratum-functionale 2b and membrane stress relaxation stratum-functionale 2c may be carried out like drawing 3, and each reaction prevention stratum functionale and the membrane stress relaxation stratum functionale may consist of two or more film with each same function. It is precise and adhesion stratum-functionale 2a has the desirable thing which was formed by the spatter, CVD, etc. from the point of a mechanical strength and which is the high film of adhesion force. In order not to produce the stress distribution in about 1 micrometer and the film, as for thickness, it is desirable more preferably that it is 0.1 micrometers or less. For this reason, the thickness of the adhesion stratum functionale of this invention is the single crystal thin film which is a metal oxide film 0.1 micrometers or less preferably, and grew epitaxially to the orientation film or a substrate 1 micrometer or less.

[0022] As for reaction prevention stratum-functionale 2b, it is desirable that it is the precise film formed by the spatter, CVD, etc. in order to prevent the lead diffusion from PZT which constitutes electric-machine conversion layer. As for thickness, it is more preferably desirable too that it is 0.1 micrometers or less about 1 micrometer. For this reason, the thickness of said adhesion stratum functionale of this invention is the single crystal thin film which is a metal oxide film 0.1 micrometers or less preferably, and grew epitaxially to the orientation film or a substrate 1 micrometer or less. or [that membrane stress relaxation stratum-functionale 2c negates the stress produced on the precise film] -- or it consists of the porosity or the amorphous film to absorb. Although about 10 micrometers may be formed by the spatter, CVD, the sol-gel method, and print processes, it is desirable that membranes are formed by 1 micrometer or less by the spatter, CVD, etc. from a mechanical strength, productivity, and an actuator property. For this reason, said reaction prevention stratum functionale of this invention is a metal oxide film 0.2 micrometers or less preferably [2 micrometers or less of thickness per layer], and consists of crystal film with a magnitude [of the microcrystal which can be found from XRD diffraction] of 50nm or more. In PZT burning temperature, it has resistance in an interlayer ingredient enough, and reactivity is low to lead and it is also desirable to use the partial stabilization or the zirconium dioxide film by which full stabilization was carried out

containing at least one oxide of the metal oxide film, MgO and GeO₂, which has a high mechanical strength, Y₂O₃, aluminum₂O₃, SrTiO₃, MgO-aluminum 2O₃, an yttrium with higher toughness, a cerium, magnesium, and calcium. [for example,] Moreover, as shown in the below-mentioned example, as for all the functional film that constitutes an interlayer, it is desirable to be formed by the common membrane formation approaches, such as a spatter, using the same ingredient at the point of productivity.

[0023] (Example 1) Substrate temperature (850,650,500,150 degrees C) was changed using RF magnetron sputtering, introducing oxygen and an argon on Si (100) substrate, and the zirconium dioxide (8mol%Y₂O₃-ZrO₂) film (with, YSZ) stabilized with the yttrium was formed by 1000Å in thickness. The result of having torn off the substrate adhesion force of each film and having measured it using law is shown in Table 1. The crystallinity of the YSZ film was so good that the substrate temperature at the time of membrane formation was high, and adhesion force also improved in connection with it. For example, when moving part is asked for the mechanical strength which can be equal to the drive with high frequency like an ink jet head, the high film of crystalline good adhesion force like the single crystal thin film which grew epitaxially to the orientation film or a substrate is desirable.

[0024]

[Table 1]

表1. 膜付着力と成膜基板温度（結晶性）の相關

基板温度 (°C)	結晶性(結晶子大きさ)	付着力 (MPa)
150	非晶質 (- Å)	120
500	多結晶 (150Å)	160
650	配向膜 (500Å)	420
850	エピタキシャル膜 (600Å)	500 上

[0025] (Example 2) In order to investigate the reactant correlation with the crystallinity of the reaction prevention film, and lead, the zirconium dioxide (40mol%CeO₂-ZrO₂) stabilized with cerium oxide was formed using RF magnetron sputtering, introducing oxygen and an argon on Si wafer (100) (substrate temperature of 850,650,500,150 degrees C). After printing a PbO paste and heating it 900 degrees C on the produced CeO₂-ZrO₂/Si film for 2 hours, SIMS is used, and it is ** BE ** about lead diffusion of the depth direction. The result is shown in drawing 4. Consequently, the lead diffusion depth at the time of forming membranes at 800 degrees C was the smallest at about 400Å, membrane formation temperature was high, and the reaction prevention effectiveness that the crystalline (the XRD:RC method estimates) better film was more expensive was acquired.

[0026] (Example 3) Next, in order to investigate the effectiveness of the membrane stress relaxation stratum functionale, 0.1-micrometer epitaxial growth of the YSZ (80mol%Y₂O₃-ZrO₂) film is first carried out by the spatter on 4 inches Si wafer (100) on the substrate temperature of 850 degrees C, and the membrane formation conditions of a 1x10 to 1 Pa pressure. Introducing oxygen, an argon, and nitrogen on it, by the substrate temperature of 750 degrees C, and the pressure of 2Pa (Ar:O₂:N₂ = 8:1:1), thickness is changed and the porous YSZ film is formed. 0.2 micrometers of precise YSZ film were further formed on it on the substrate temperature of 850 degrees C, and the membrane formation conditions of a 1x10 to 5 Pa pressure. The radius of curvature (the amount of substrate deflections) of Si wafer with which the laminating of the YSZ bipolar membrane was carried out is measured by Newton's ring observation, and the result of having investigated correlation of membrane stress relaxation functional layer membrane thickness and a membrane stress relaxation effect is shown in drawing 5. When the porous membrane stress relaxation stratum functionale was not used, the compressive stress which was being committed to YSZ bipolar membrane was eased by forming the membrane stress relaxation stratum functionale in between, and the substrate deflection of Si wafer decreased. When it thinks from the point of an interlayer's mechanical strength, as for the thickness of the membrane stress relaxation stratum functionale per layer, it is desirable that it is 1 micrometer or less.

[0027] (Example 4) In the YSZ film by which the laminating was carried out on the single crystal

Si substrate given in an example 3, on the interlayer / Si substrate which set the membrane stress relaxation stratum functionale to 0.5 micrometers, a platinum paste is screen-stenciled and 5 micrometers lower electrode 3a is formed. Then, 0.5Pb(nickel1/3Nb 2/3) O3-0.5Pb (Zr0.7Ti0.3) O3 (it abbreviates to PNN-PZT hereafter) is screen-stenciled as a piezoelectric material on a lower electrode, and it calcinates at the temperature of 900 degrees C in atmospheric air in desiccation and a firing furnace for 2 hours for 30 minutes by 150 degrees C. The same PNN-PZT capacitor as the electrostrictive actuator configuration which formed silver-palladium by baking by screen-stencil, and showed up electrode 3b by drawing 1 is produced after PNN-PZT baking. Moreover, the same capacitor was formed on the YSZ (Serra FREX A) substrate (100 micrometers of board thickness) by the Japanese fine-ceramics company, and specific inductive capacity was measured and compared, respectively. Consequently, also by PZT formed on a YSZ interlayer / Si, the lead diffusion to Si substrate was not seen, but the good value of specific inductive capacity (ϵ =2000) almost comparable as PZT formed on the YSZ substrate was acquired. This means that thick-film PNN-PZT which shows a good piezo-electric property has formed on Si substrate.

[0028] (Example 5) When sputtering is used for interlayer formation, an epitaxial film, the orientation film, the amorphous film, and porous membrane can be easily formed only by changing substrate temperature, gas pressure, and a gas value with the same target. As shown in the example 3, it is possible to form each stratum functionale continuously with such combination, and the point of manufacture effectiveness to spatter membrane formation is desirable.

[0029]

[Effect of the Invention] Effectiveness corresponding to claim 1 : In the electrostrictive actuator which can apply this invention By constituting the interlayer between a base / electric - machine conversion layer from the monolayer or double layer which has an adhesion function, a reaction prevention function, and a membrane stress relaxation function The lead diffusion from electric-machine conversion layer can be prevented, base adhesion force can ease the middle class's compressive stress strongly, and offer ***** can do the electrostrictive actuator of reliable high performance by it.

[0030] Effectiveness corresponding to claim 2: By forming the high base adhesion layer of a precise mechanical strength, the electrostrictive actuator equipped with the more reliable middle class is realizable.

[0031] Effectiveness corresponding to claim 3: By forming the precise reaction prevention stratum functionale, the actuator with which the reaction prevention effectiveness between a piezoelectric-material layer and a base was equipped with the middle class reliable high more is realizable.

[0032] Effectiveness corresponding to claim 4: By forming porosity or the membrane stress relaxation stratum functionale which becomes since amorphous, the whole middle class's membrane stress can be eased and the actuator equipped with the more reliable middle class can be realized.

[0033] Effectiveness corresponding to claim 5: By constituting from a zirconium dioxide by which stabilization or partial stabilization was carried out as a middle class ingredient, the actuator with which a mechanical strength and toughness were equipped with the middle class of high high-reliability and high performance is realizable.

[0034] The operation effectiveness of claim 6: By forming the zirconium dioxide film which serves as the middle class by the spatter, dependability can produce the cheap high middle class of cost.

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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1] It is drawing showing roughly the piezoelectric-device unit which can apply this invention.

[Drawing 2] It is drawing showing roughly the ink jet piezo-electricity head using the piezoelectric-device unit of this invention.

[Drawing 3] It is the same drawing as drawing 1 which shows other examples of a piezoelectric-device unit.

[Drawing 4] It is drawing showing correlation of the membrane formation temperature of a substrate, and the lead diffusion depth.

[Drawing 5] It is drawing showing the thickness of the membrane stress relaxation stratum functionale, and correlation of a membrane stress relaxation effect.

[Description of Notations]

1 [-- The reaction prevention stratum functionale 2c / -- The membrane stress relaxation stratum functionale, 3 / -- An electrode, 3a / -- A bottom electrode, 3b / -- A top electrode, 4 / -- A piezoelectric-material layer, 5 / -- A pressure room, 6 / -- A nozzle plate, 7 / -- Nozzle.] -- A base, 2 -- An interlayer, 2a -- The adhesion stratum functionale, 2b

(19)日本国特許庁 (JP)

(12) **公開特許公報 (A)**

(11)特許出願公開番号

特開平11-204849

(43)公開日 平成11年(1999)7月30日

(51)Int.Cl.⁶

H 01 L 41/09

B 41 J 2/045

2/055

2/16

C 04 B 35/48

識別記号

F 1

H 01 L 41/08

C

B 41 J 3/04

103A

103H

C 04 B 35/48

D

H 01 L 41/22

Z

審査請求 未請求 請求項の数 6 OL (全 6 頁) 最終頁に続く

(21)出願番号

特願平10-8232

(22)出願日

平成10年(1998)1月20日

(71)出願人 000006747

株式会社リコー

東京都大田区中馬込1丁目3番6号

(72)発明者 木幡 八州太郎

東京都大田区中馬込1丁目3番6号 株式会社リコー内

(72)発明者 藤沢 悅子

東京都大田区中馬込1丁目3番6号 株式会社リコー内

(72)発明者 秋山 善一

東京都大田区中馬込1丁目3番6号 株式会社リコー内

(74)代理人 弁理士 高野 明近 (外1名)

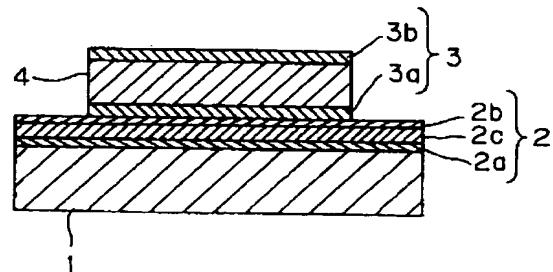
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(54)【発明の名称】 圧電アクチュエータ

(57)【要約】

【課題】 Si基板上での鉛系圧電セラミック材料の焼結時の基板上への鉛拡散を防止でき、しかも機械的強度及び信頼性の高い中間層を持ったアクチュエータを実現する。

【解決手段】 Si基板上に、上下電極および該電極間に挟まれた電気-機械変換効果を示す圧電材料層からなる電気-機械変換素子部を配し、与えられる電気信号に応じて基体の一部を変形する圧電アクチュエータにおいて、前記基体と前記電気-機械変換素子部の間に1層以上を中間層を形成し、該中間層を、基体との密着機能層、反応防止機能層、膜応力緩和機能層を有する単層または複数層から構成した。



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チングによりSi基板にインク滴吐出のための加圧室を形成し、さらに圧電膜直下のSiO₂膜をBHFにより除去し、圧電膜とSi基板の相互拡散による影響を無視できる構成および製造方法を提案している。

【0004】特願平9-107296号では、単結晶Si基板上に、部分または完全安定化された酸化ジルコニア膜、酸化セリウム膜等の緻密な鉛拡散防止膜を形成し、圧電膜直下のSiを残すインクジェットヘッドの構成を提案している。

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【0005】

【発明が解決しようとする課題】電気-機械変換素子の圧電材料層にはチタン酸ジルコン鉛（以下PZT）等の鉛系圧電セラミックス材料が多く用いられる。しかし、例えば、Si基板上にPZTを形成した後、焼結のための高温でのアニールを行うと、Si基板上に鉛が拡散し、Si基板表面に形成しているSiO₂の融点降下による融解が発生する。

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【0006】特開平8-252914号公報では、圧電膜直下のSi基板およびSiO₂膜をエッチング等で完全に取り除いてインク加圧室を形成することにより、上記問題を解決した発明が開示されているが、この発明では弾性膜と電極膜のみで加圧を行うため、機械的強度が弱くなるという問題がある。

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【0007】特願平9-107296号では、鉛拡散を防止する緻密な部分または完全安定化された酸化ジルコニア膜、酸化セリウム膜等からなる中間層を、電気-機械変換素子と加圧室基板の間に形成し、加圧室部の薄肉厚部を1~20μmにすることにより、振動板に求められる機械強度と、電気-機械変換部の歪みの効果的な伝達を行うことができる発明が開示されている。しかし、鉛拡散を防ぐため、例えば、エピタキシャル膜のような緻密で結晶性の良い単層で中間層を形成する場合、欠陥もピンホールもない完全な単結晶膜ならば、0.1μm程度でも可能であるが、実際はピンホールや結晶欠陥等の膜欠陥が発生し、そこからSi基板への鉛拡散が進む。一方、鉛拡散を防止できる緻密な膜を単層または複層で厚く形成した場合には、圧電素子焼成等の熱履歴によって膜表面からクラックが進み、Si基板への鉛拡散が発生する。さらに膜応力によるSi振動板のたわみが発生し、安定したインク滴吐出が難しくなり、ピットごとにばらつきが生ずるという問題がある。

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【0008】本発明では、基体との密着機能層、反応防止機能層、膜応力緩和機能層を有する単層または複数層から、十分な機械的強度を有した信頼性の高い基体界面中間層を形成し、それと電気-機械変換素子を用いた圧電アクチュエータを提供することを主なる目的とする。請求項2の発明は、金属酸化物からなる配向膜、もしくは基板に対しエピタキシャル成長した単結晶薄膜であることを特徴とする付着力が大きい基体密着機能層を配置させることで、機械的強度の高い中間層を形成すること

【特許請求の範囲】

【請求項1】 基体上に、上下電極および該電極間に挿まれた電気-機械変換効果を示す圧電材料層からなり、与えられる電気信号に応じて基体の一部を変形する電気-機械変換素子部を配し、基体と電気-機械変換素子部の間に1層以上の中間層が形成されている圧電アクチュエータにおいて、該中間層が基体との密着機能層、反応防止機能層、膜応力緩和機能層を有する単層または複数層から構成されることを特徴とした圧電アクチュエータ。

【請求項2】 請求項1記載の圧電アクチュエータにおいて、前記密着機能層の膜厚は、1μm以下好ましくは0.1μm以下の金属酸化膜であり、配向膜もしくは基板に対しエピタキシャル成長した単結晶薄膜であることを特徴とする圧電アクチュエータ。

【請求項3】 請求項1記載の圧電アクチュエータにおいて、前記反応防止機能層は、1層当たり膜厚2μm以下好ましくは0.2μm以下の金属酸化膜であり、XRD回折より求まる結晶子の大きさ50nm以上の結晶膜からなることを特徴とする圧電アクチュエータ。

【請求項4】 請求項1記載の圧電アクチュエータにおいて、前記膜応力緩和機能層は、1層当たり膜厚10μm以下好ましくは1μm以下の金属酸化膜であり、多孔質もしくは非晶質からなることを特徴とした圧電アクチュエータ。

【請求項5】 請求項1乃至4のいずれかに記載の圧電アクチュエータにおいて、前記中間層がイットリウム、セリウム、マグネシウム、カルシウムの酸化物を少なくとも一つ含んだ部分安定化または完全安定化された酸化ジルコニア膜であることを特徴とする圧電アクチュエータ。

【請求項6】 請求項5記載の酸化ジルコニア膜をスパッタリングにより成膜することを特徴とする圧電アクチュエータの中間層の作製方法。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、Si基板上に形成する圧電素子および圧電素子を用いた圧電アクチュエータに関するものである。

【0002】

【従来の技術】圧電/電歪素子の用途として、加圧室に圧力を加えてインク滴を吐出する圧電インクジェットヘッドがある。近年、インクジェットヘッドは高集積化が求められており、半導体プロセスやマイクロマシニング技術により、エッチング技術が確立されていて、かつ、コストの安いSi基板に加圧室を形成するアクチュエータ構成が考案されている。

【0003】特開平8-252914号公報のインクジェットヘッドでは、単結晶Si基板上にSiO₂膜を形成し、弾性膜・圧電/電歪層を積層した後、異方性エッ

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を目的とする。

【0009】請求項3の発明は、反応防止機能層として緻密な結晶性の良い金属酸化物膜を用いることにより、圧電材料層と基体間の反応防止効果の高い中間層を形成することを目的とする。請求項4の発明は、高温で緻密な反応防止膜、密着機能膜を形成することから生ずる膜応力を打ち消すまたは緩和する膜応力緩和機能層を配置させることで、中間層全体の応力を軽減させることを目的とする。

【0010】請求項5の発明は、中間層材料として部分または完全安定化された酸化ジルコニウム膜を用いることにより、より韌性・機械的強度の高い中間層を形成することを目的とする。請求項6の発明は、中間層形成にスパッタリングを用いることにより、より効率的に中間層を形成することを目的とする。

【0011】

【課題を解決するための手段】請求項1の発明は、基体上に、上下電極および該電極間に挟まれた電気-機械変換効果を示す圧電材料層からなり、与えられる電気信号に応じて基体の一部を変形する電気-機械変換素子部を配し、基体と電気-機械変換素子部の間に1層以上の中間層が形成されている圧電アクチュエータにおいて、該中間層が基体との密着機能層、反応防止機能層、膜応力緩和機能層を有する単層または複数層から構成される圧電アクチュエータである。

【0012】請求項2の発明は、請求項1記載の圧電アクチュエータにおいて、前記密着機能層の膜厚は、1μm以下好ましくは0.1μm以下の金属酸化膜であり、配向膜もしくは基板に対しエピタキシャル成長した単結晶薄膜である圧電アクチュエータである。

【0013】請求項3の発明は、請求項1記載の圧電アクチュエータにおいて、前記反応防止機能層は、1層当たり膜厚2μm以下好ましくは0.2μm以下の金属酸化膜であり、XRD回折より求まる結晶子の大きさ50nm以上の結晶膜からなる圧電アクチュエータである。

【0014】請求項4の発明は、請求項1記載の圧電アクチュエータにおいて、前記膜応力緩和機能層は、1層当たり膜厚10μm以下好ましくは1μm以下の金属酸化膜であり、多孔質もしくは非晶質からなる圧電アクチュエータである。

【0015】請求項5の発明は、請求項1乃至4のいずれかに記載の圧電アクチュエータにおいて、前記中間層がイットリウム、セリウム、マグネシウム、カルシウムの酸化物を少なくとも一つ含んだ部分安定化または完全安定化された酸化ジルコニウム膜である圧電アクチュエータである。

【0016】請求項6の発明は、請求項5記載の酸化ジルコニウム膜をスパッタリングにより成膜する圧電アクチュエータの中間層の作製方法である。

【0017】

【発明の実施の形態】以下に、図面を参照して本発明の構成を説明する。図1に本発明が適用可能な圧電素子ユニットの概略図を示す。基体1上に、中間層2と上下電極3a, 3b間に挟まれた電気機械変換効果を示す圧電材料層4が形成され、電界印加に対して基体の一部を変形させる。さらに、図2に示すように、基板1の一部に圧電素子に対応して圧力室5を形成し、ノズルプレート6を接合した場合、電極への電界印加によってノズル7から圧力室中のインクが吐出されるインクジェット圧電ヘッドが構成される。

【0018】基体1は加工性に優れ、機械的強度が高く、熱処理・焼成温度で不活性の材料であれば、特に規制されるものではなく、Si基体であっても、セラミックスであっても、金属であってもよく、また、複数の材料による構造体から構成されていてもよい。

【0019】電極材料としては熱処理・焼成温度での高温酸化雰囲気に耐える導体であればよく、白金や白金族元素(Pd, Rh, Ir, Ru)などの高温融点貴金属類、およびそれらの合金を主成分とする電極材料が安定性の点からもっとも好ましい。

【0020】下部電極層上の圧電材料層4には、PZT系セラミックスが好ましく、スクリーン印刷法を用いて、一回の印刷工程で10ないし20μmの膜厚を形成できる。乾燥後、700～1000℃の温度で大気中にて焼成される。

【0021】中間層2は基体1との密着機能層2a、反応防止機能層2bおよび膜応力緩和機能層2cから構成される。反応防止効果を高めるため、反応防止機能層2bおよび膜応力緩和機能層2cは、図3のように複数積層されてもよく、また、一つ一つの反応防止機能層、膜応力緩和機能層は、それぞれの同様の機能を持つ複数膜から構成されていても良い。密着機能層2aは、機械的強度の点から、スパッタやCVD等で成膜された緻密で付着力の高い膜であることが望ましい。膜厚は1μm程度、膜内の応力分布を生じさせないためには、より好ましくは、0.1μm以下であることが好ましい。このため本発明の密着機能層の膜厚は、1μm以下好ましくは0.1μm以下の金属酸化膜であり、配向膜もしくは基板に対しエピタキシャル成長した単結晶薄膜である。

【0022】反応防止機能層2bは、電気-機械変換層を構成するPZTからの鉛拡散を防止するため、スパッタやCVD等で成膜された緻密な膜であることが望ましい。膜厚はやはり1μm程度、より好ましくは0.1μm以下であることが好ましい。このため本発明の前記密着機能層の膜厚は、1μm以下好ましくは0.1μm以下の金属酸化膜であり、配向膜もしくは基板に対しエピタキシャル成長した単結晶薄膜である。膜応力緩和機能層2cは、緻密な膜に生じた応力を打ち消すかまたは吸収する、多孔質または非晶質の膜から構成される。スパッタ、CVD、sol-gel法、また印刷法で10μ

m程度形成されても構わないが、機械的強度、生産性、アクチュエータ特性からスパッタ、CVD等で1 μm以下で成膜されることが好ましい。このため本発明の前記反応防止機能層は、1層当たり膜厚2 μm以下好ましくは0.2 μm以下の金属酸化膜であり、XRD回折より求まる結晶子の大きさ50 nm以上の結晶膜からなる。中間層材料には、PZT焼成温度において十分耐性を持ち、鉛に対して反応性が低く、高い機械的強度を有する金属酸化膜、例えば、MgO, GeO₂, Y₂O₃, Al₂O₃, SrTiO₃, MgO-Al₂O₃や、より高い韌性を持つイットリウム、セリウム、マグネシウム、カルシウムの酸化物を少なくとも一つ含んだ部分安定化または完全安定化された酸化ジルコニウム膜を用いることも好ましい。また、後述の実施例に示すように、中間層を構成するすべての機能膜は、生産性の点では同一材料を用いて、スパッタ等の共通の成膜方法で形成されることが*

表1. 附着力と成膜基板温度(結晶性)の相関

基板温度(℃)	結晶性(結晶子大きさ)	付着力(MPa)
150	非晶質(-A)	120
500	多結晶(150 Å)	160
650	配向膜(500 Å)	420
850	エピタキシャル膜(600 Å)	500上

【0025】(実施例2) 反応防止膜の結晶性と鉛との反応性の相関を調べるため、Siウェハ(100)上に、酸素とアルゴンを導入しながらRFマグネットロンスパッタを用いて、酸化セリウムで安定化させた酸化ジルコニウム(40 mol% CeO₂-ZrO₂)を成膜した(基板温度850, 650, 500, 150℃)。作製されたCeO₂-ZrO₂/Si膜にPbOペーストを印刷し、900℃2時間加熱した後、SIMSを用いて深さ方向の鉛拡散について調べた。その結果を図4に示す。その結果、800℃で成膜した場合の鉛拡散深さが400 Å程度で最も小さく、成膜温度が高く、結晶性(XRD: R C法で評価)の良い膜ほど高い反応防止効果が得られた。

【0026】(実施例3) 次に、膜応力緩和機能層の効果を調べるため、まず、4インチのSiウェハ(100)上に、基板温度850℃、圧力1×10⁻¹ Paの成膜条件で、スパッタによりYSZ(80 mol% Y₂O₃-ZrO₂)膜を0.1 μmエピタキシャル成長させる。その上に酸素とアルゴンと窒素を導入しながら、基板温度750℃、圧力2 Pa(Ar:O₂:N₂=8:1:1)で、多孔質のYSZ膜を膜厚を変化させて形成する。その上にさらに基板温度850℃、圧力1×10⁻¹ Paの成膜条件で緻密なYSZ膜を0.2 μm形成した。YSZ複合膜の積層されたSiウェハの曲率半径(基板たわみ量)をニュートン環観察により測定し、膜応力緩和機能層膜厚と膜応力緩和効果の相関を調べた結果を図5に示す。多孔質の膜応力緩和機能層を用いない場合に、YSZ複合膜に働いていた圧縮応力が、膜応力緩和機能層

* 望ましい。

【0023】(実施例1) Si(100)基板上に、酸素とアルゴンを導入しながらRFマグネットロンスパッタを用いて、基板温度(850, 650, 500, 150℃)を変化させて、イットリウムで安定化された酸化ジルコニウム(8 mol% Y₂O₃-ZrO₂)膜(以YSZ)を厚さ1000 Åで成膜した。それぞれの膜の基板付着力を、引き剥がし法を用いて測定した結果を表1に示す。成膜時の基板温度が高いほどYSZ膜の結晶性がよく、それに伴い付着力も向上した。例えば、インクジェットヘッドのような高周波数での駆動に耐え得る機械的強度が可動部に求められる場合、配向膜または基板に対しエピタキシャル成長した単結晶薄膜のような結晶性の良い付着力の高い膜が好ましい。

【0024】

【表1】

を間に形成することで緩和され、Siウェハの基板たわみが少なくなった。中間層の機械的強度という点からを考えると、1層当たりの膜応力緩和機能層の膜厚は1 μm以下であることが好ましい。

【0027】(実施例4) 実施例3に記載の単結晶Si基板上に積層されたYSZ膜において、膜応力緩和機能層を0.5 μmとした中間層/Si基板上に白金ペーストをスクリーン印刷し、下部電極3aを5 μm形成する。続いて下部電極上に圧電材料として0.5 Pb(Ni_{0.5}Nb_{0.5})O₃-0.5 Pb(Zr_{0.5}Ti_{0.5})O₃(以下、PNN-PZTと略す)をスクリーン印刷し、150℃で30分間乾燥、そして、焼成炉において大気中で900℃の温度で2時間焼成する。PNN-PZT焼成後、上部電極3bをスクリーン印刷で銀-パラジウムを焼き付けにより形成して、図1で示した圧電アクチュエータ構成と同様のPNN-PZTキャパシタを作製する。また、同様のキャパシタを日本ファインセラミックス社製YSZ(セラフレックスA)基板(板厚100 μm)上に形成し、それぞれ比誘電率を測定し比較した。その結果、YSZ中間層/Si上に形成したPZTでもSi基板への鉛拡散は見られず、YSZ基板上に形成されたPZTとほぼ同程度の比誘電率(ε_r=2000)という良好な値が得られた。このことは良好な圧電特性を示す厚膜PNN-PZTがSi基板上に形成できることを意味する。

【0028】(実施例5) 中間層形成にスパッタリングを用いた場合、同一ターゲットで基板温度、ガス圧、ガス値を変化させるだけで容易にエピタキシャル膜、配向

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膜、非晶質膜、多孔質膜を成膜することができる。実施例3に示したように、これらの組み合わせにより各機能層を連続的に形成することが可能であり、製造効率の点からスパッタ成膜が好ましい。

【0029】

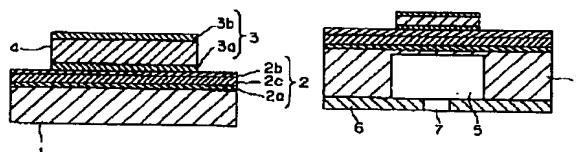
【発明の効果】請求項1に対応する効果：本発明を適用可能な圧電アクチュエータにおいて、基体／電気－機械変換層間の中間層を密着機能、反応防止機能、膜応力緩和機能を有する単層または複層で構成することにより、電気－機械変換層からの鉛拡散を防止し、基体付着力が強くかつ、中間層の圧縮応力を緩和することができ、それによって信頼性の高い高性能の圧電アクチュエータを提供することができる。

【0030】請求項2に対応する効果：緻密な機械的強度の高い基体密着層を形成することにより、より信頼性の高い中間層を備えた圧電アクチュエータを実現することができる。

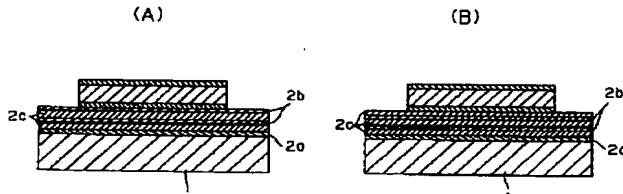
【0031】請求項3に対応する効果：緻密な反応防止機能層を形成することにより、圧電材料層と基体間の反応防止効果が高くより信頼性の高い中間層を備えたアクチュエータを実現することができる。

【0032】請求項4に対応する効果：多孔質または非晶質からなる膜応力緩和機能層を形成することにより、中間層全体の膜応力を緩和し、より信頼性の高い中間層を備えたアクチュエータを実現することができる。*

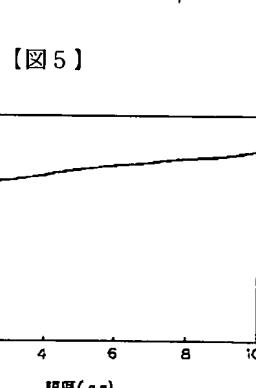
【図1】



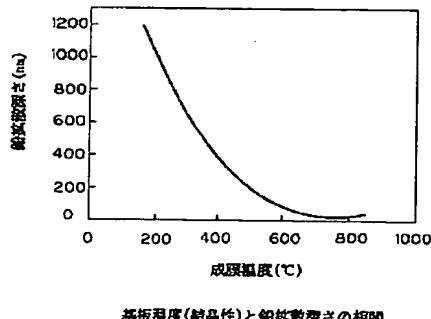
【図2】



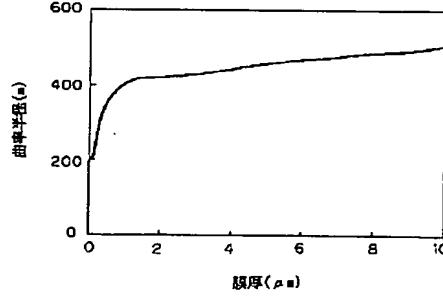
【図3】



【図4】



【図5】



(6)

特開平11-204849

フロントページの続き

(51) Int. Cl. 識別記号
H 01 L 41/22

(72) 発明者 山中 邦裕
東京都大田区中馬込1丁目3番6号 株式
会社リコー内